Noble Gas Isotope Geochemistry at the Dixie Valley Geothermal Field

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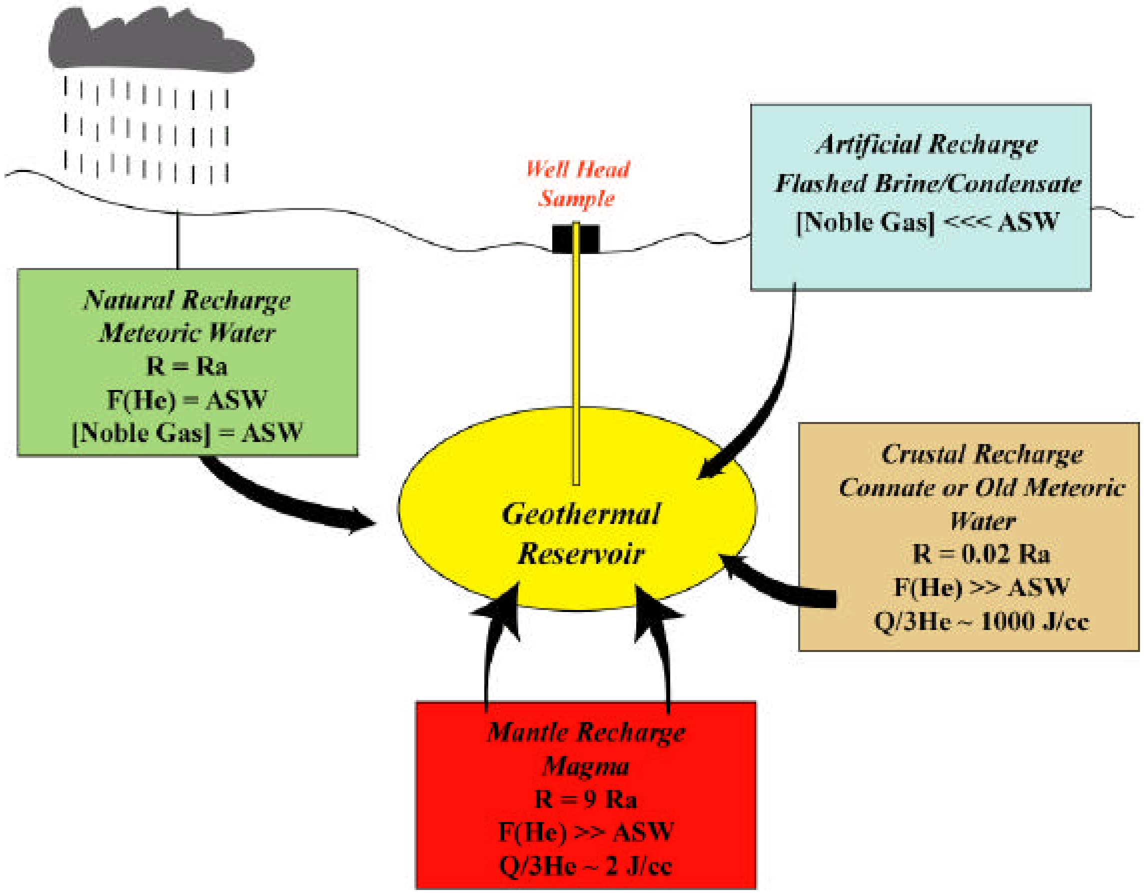
Primary Goals

(1) Identify Heat and Fluid Sources

(2) Evaluate Noble Gases as Potential Natural Tracers for Monitoring Injectate

(3) Integrate Chemical and Isotopic Data into Reservoir Simulation Models

Noble Gases
Natural Tracers for Geothermal Fluids



Noble Gases: Sensitive Natural Tracers For Detecting and Monitoring Injectate Returns to Geothermal Reservoirs

Proof of Concept

Natural Injectate Tracers

- **Chloride and Water Isotopes - Widely used**
  - **Must assume single indigenous reservoir fluid**
  - **Only applicable in single phase liquid systems**
  - **Inapplicable in systems with high TDS**
  - **Low sensitivity: Injectate concentrations are similar to production fluids**
    - **With 25% steam fraction:**

      --- [Cl] (injectate) ~ 1.30 [Cl] (production fluid)

      --- D(d^{18}O) ~ 1-2 ‰

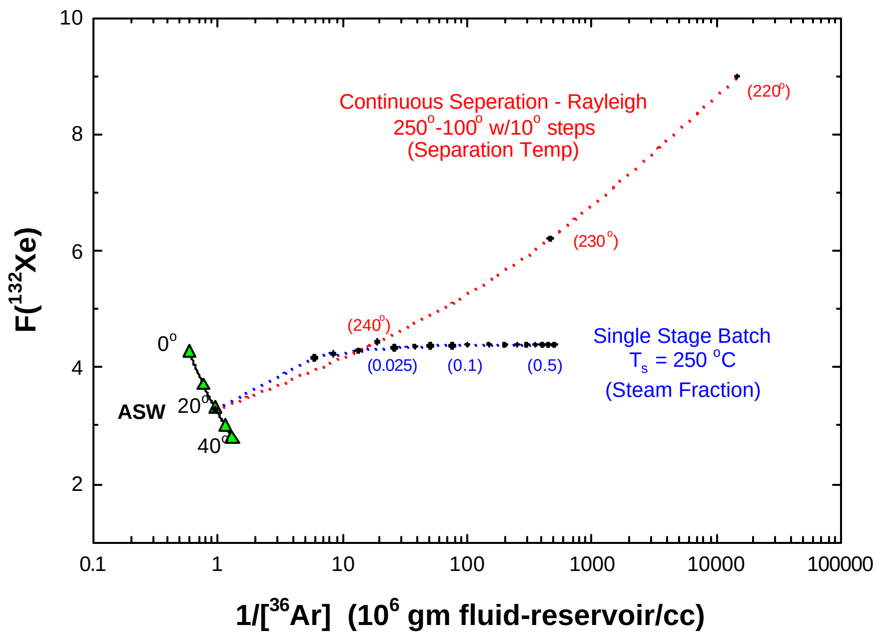
- **Noble Gases**
  - **Predictable and relatively invariant composition and concentration in the indigenous reservoir fluids.**
  - **High sensitivity: Injectate concentrations are extremely low**
    - **With 25% steam fraction**

      --- [Noble Gas] (injectate) ~ 0.01-0.001 [Noble Gas] (production fluid)

    - **Noble gases are ~4-40 times more sensitive.**

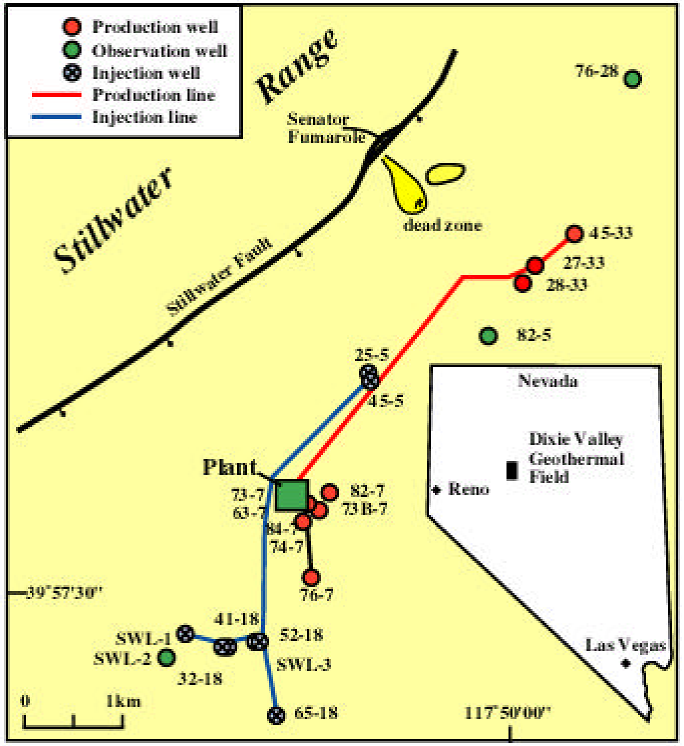
Noble Gases: Tracers for Natural Recharge and Injectate
Theory

- **Phase Separation:**
  - ♦ **Case I ® Isothermal Batch or Single Stage Separation**
  - ♦ **Case II ® Non-isothermal Continuous Steam Separation (Rayleigh Distillation).**
- **Very low solubility leads to high sensitivity for monitoring injectate return.**
- **With a steam fraction of only 2.5%: residual liquid is depleted in ^{36}Ar by factor of ~20!**
- **Ultimate composition is path dependent.**



Tracers for Re-Injected Fluids at Dixie Valley

Dixie Valley, Nevada
Geothermal Field



334.5 billion pounds of flashed brine have beeen injected into the geothermal field since September 1988

Tracers for Re-Injected Fluids at Dixie Valley

- **Composition of re-injected brine is consistent with isothermal batch separation at ~250 ^oC with ~20-30% steam fraction.**

- **Noble gases in 1998 and 1999 production fluids are significantly depleted (2-4 times) relative to 25^oC ASW.**

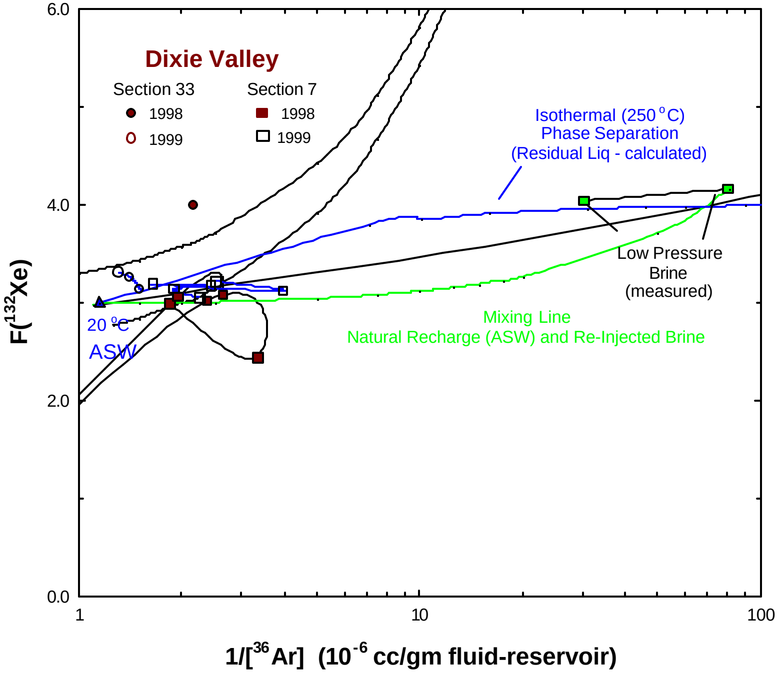
- **Composition of Section 7 wells reflect mixing of re-injected brine and meteoric water.**

- **Volume fraction of injectate in production stream:**

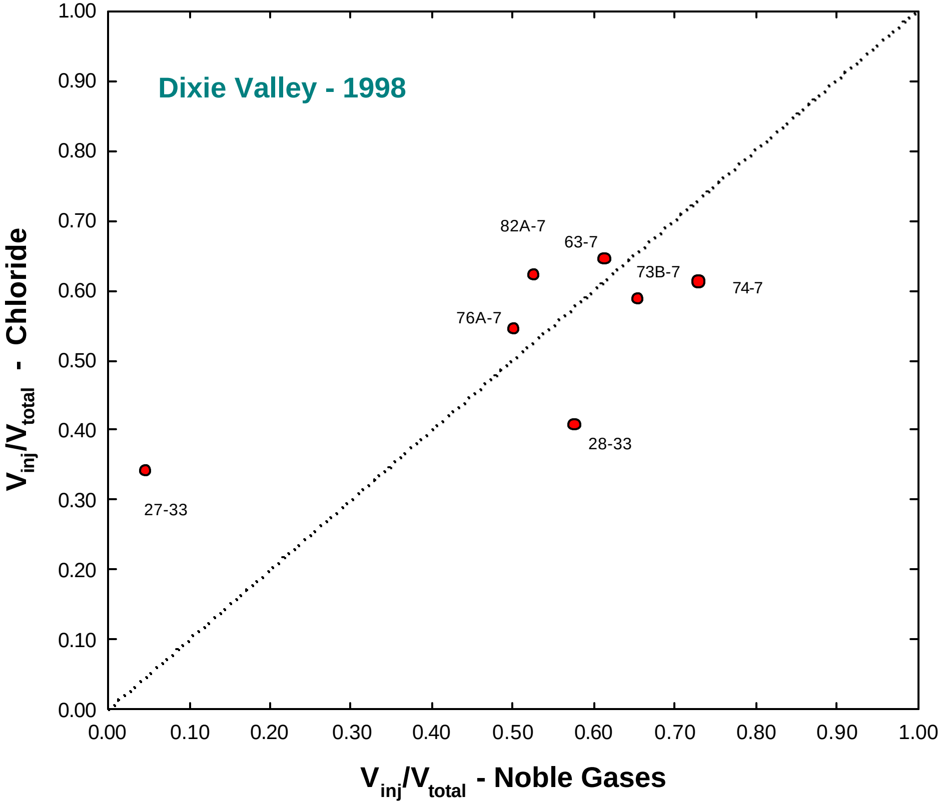
  Section 33 ~30-35%

  Section 7 ~50-80%

Noble Gases: Tracers For Re-Injected Brine

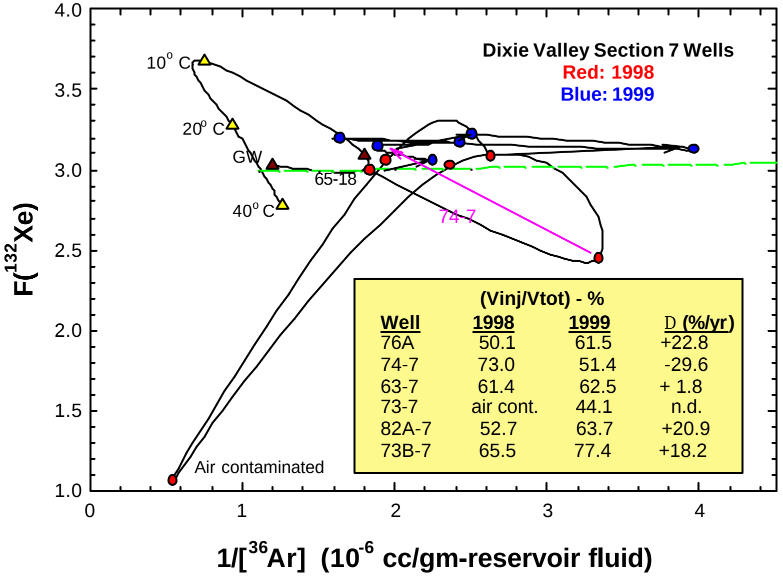


Tracers for Re-Injected Fluids at Dixie Valley



Section 7 Wells
1998 to 1999

- **[^{36}Ar] declined from 1998 to 1999 in all but one well (74-7).**
- **Relative proportion of co-produced injectate increased at constant rate:**
  - **D(Vinj/Vtot) ~ 20%/year**
- **Exception (74-7): [^{36}Ar] increased by factor of ~2.**
  - **Cold groundwater added to injectate beginning mid-1997 (Well 65-18)**

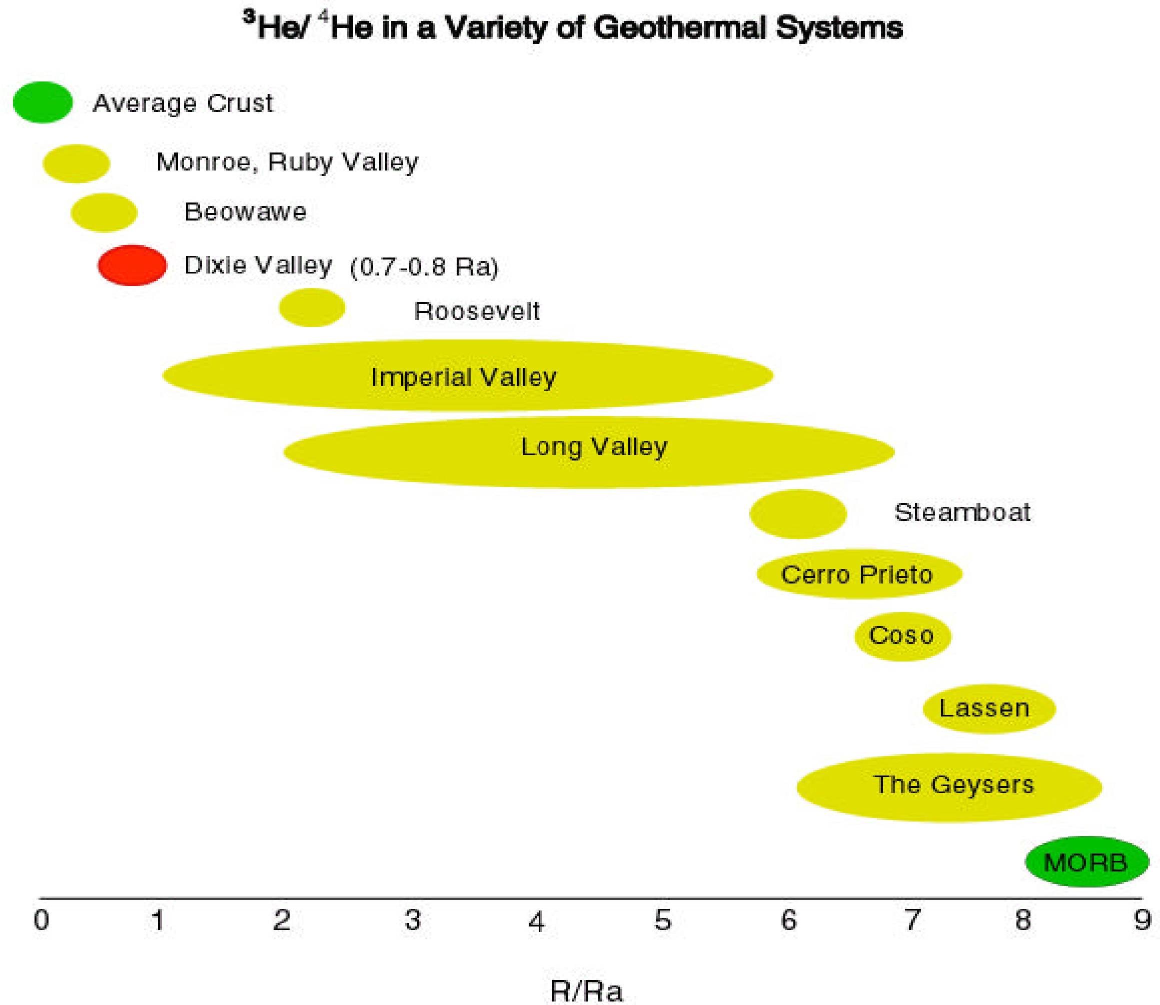


(Vinj/Vtot) - %			
Well	**1998**	**1999**	**D (%/yr)**
76A	50.1	61.5	+22.8
74-7	73.0	51.4	-29.6
63-7	61.4	62.5	+ 1.8
73-7	air cont.	44.1	n.d.
82A-7	52.7	63.7	+20.9
73B-7	65.5	77.4	+18.2

Helium Isotopes in
Dixie Valley Wells, Springs and Fumaroles

Heat and Fluid sources

Helium Isotopes in Geothermal Systems



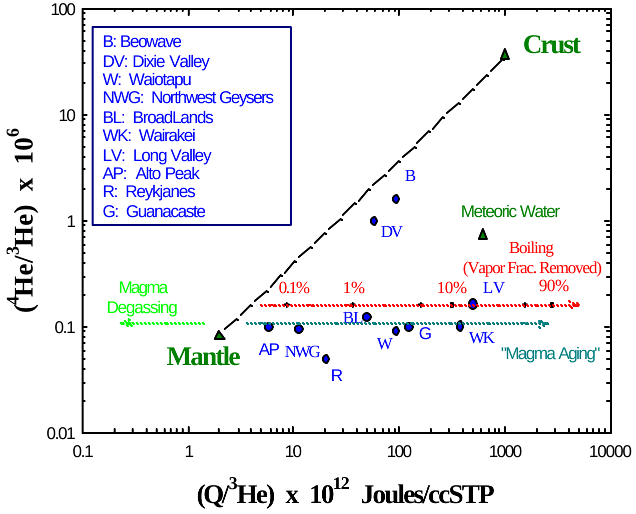
Coupling of Heat and Helium

- **~75% of Earth's heat budget is from natural radio-decay of U and Th --- leads to well defined ($^4He/^3He$) and Q(heat)/^3He ratios for mantle and crustal fluids (green triangles)**

- **Using this coherence, the heat source of a geothermal reservoir can be evaluated:**
  - **Dixie Valley = 10-15% of heat derived from mantle - remainder is derived from the crustal geothermal gradient**
  - **NW Geysers = 100%**

- **Heat loss by conduction, boiling, or mixing will shift the helium isotopic composition and Heat/^3He ratios in predictable ways --- allowing present state of a geothermal reservoir to be ascertained.**

Helium and Heat
In Geothermal Systems



1-D Fluid Flow Model
Through Range Front Fault

- **Steady state 1-d advection (no dispersion) upward flow scaled to crustal thickness:**

$$q = \frac{H_{crust} * \rho_s * P(He)}{\rho_f * [^4He]_{f,mantle}} \left[\frac{(R/Ra)_{meas} - (R/Ra)_{crust}}{(R/Ra)_{mant} - (R/Ra)_{meas}} \right]$$

q = fluid upflow rate in fault zone

H_{crust} = thickness of brittle + ductile crust

r_s, r_f **= density of solid and fluid**

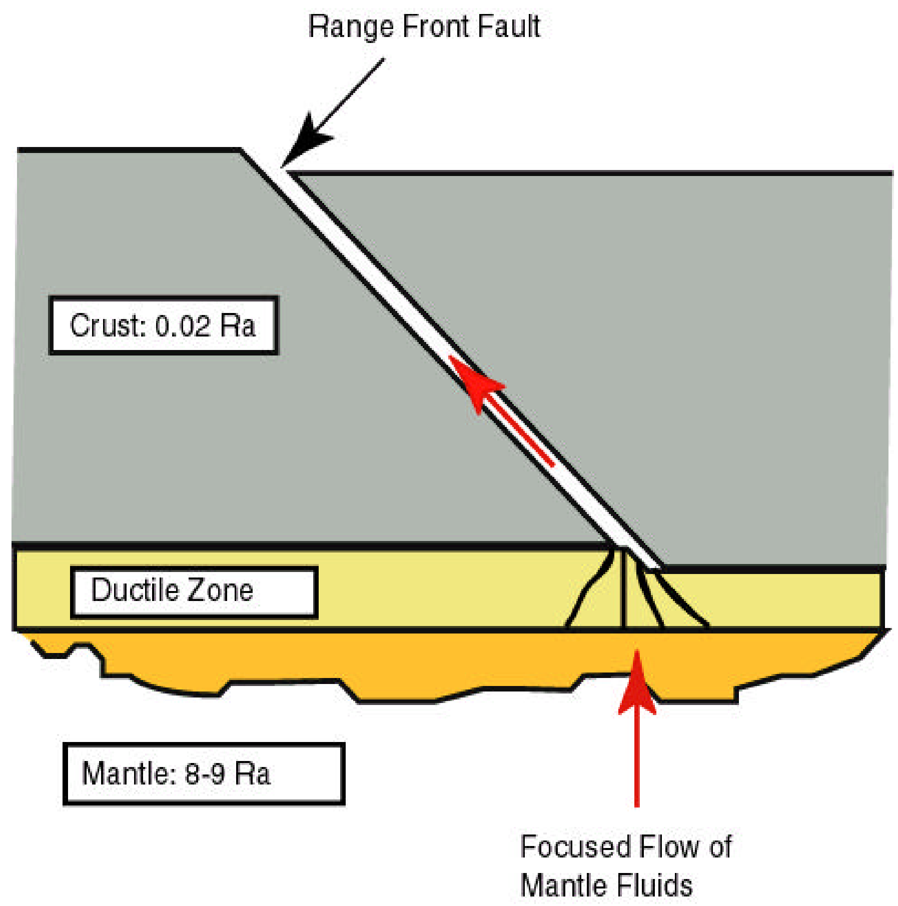
P(He) = present day ^{4}He production rate from U+Th in fault zone minerals

(R/Ra) = helium isotopic composition

[^{4}He]$_{f,mantle}$ = original ^{4}He concentration in the upwelling mantle fluid Calculated from ^{3}He in measured fluid.

- **Dixie Valley geothermal wells (H_{crust} = 15 km; [U] = 1 ppm):**

q ~ 0.5 mm/yr



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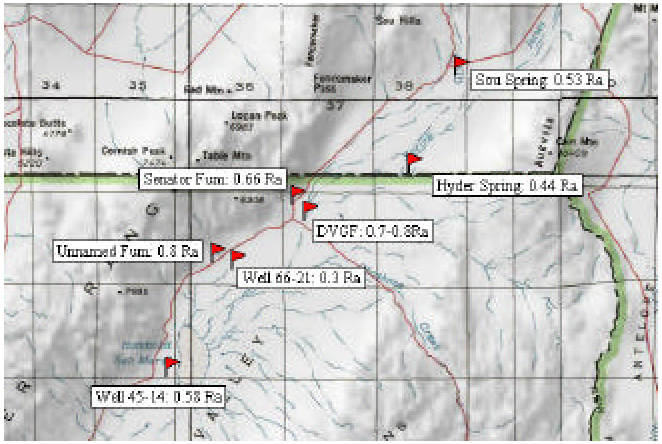
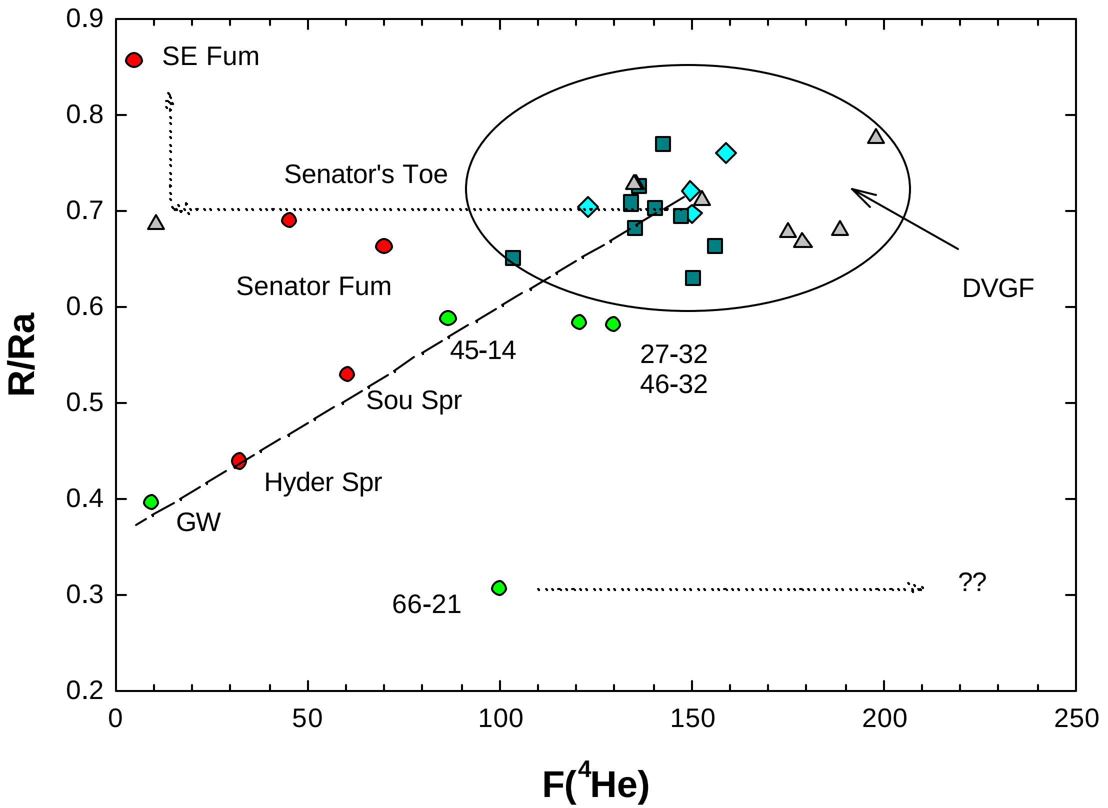


Fluid Mixing



Summary

- **Identifying and Monitoring Re-Injected Fluids**
  - **Noble gases compliment traditional conservative tracers by providing a more sensitive quantitative monitoring tool.**
  - **Section 7 Wells: ~50-80% injectate and increasing ~20%/year**

- **Heat and Fluid Sources**
  - **~10-15% of heat derived from mantle, remainder from crustal geothermal gradient.**
  - **Helium isotopes imply vertical flow rates of mantle fluids through the range front fault of ~0.5 mm/yr.**
  - **Helium abundances and isotopic compositions require that Dixie Valley thermal waters are a mixture of shallow young groundwater and a deeper fluid indistinguishable from the fluids produced in the Geothermal field.**